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(71) Applicant (*for all designated States except US*): **KONINKLIJKE PHILIPS ELECTRONICS N.V.** [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **GERARD, Olivier** [FR/FR]; c/o Société Civile SPID, 156 Boulevard Haussmann, F-75008 PARIS (FR). **FLORENT, Raoul** [FR/FR]; c/o Société Civile SPID, 156 Boulevard Haussmann, F-75008 PARIS (FR).

(74) Agent: **CHAFFRAIX, Jean**; Société Civile SPID, 156 Boulevard Haussmann, F-75008 Paris (FR).

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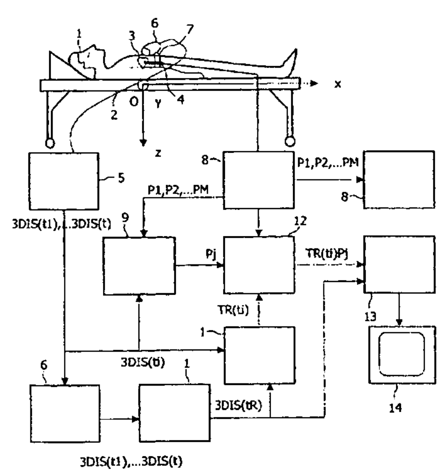
(54) Title: A MEDICAL IMAGING SYSTEM FOR MAPPING A STRUCTURE IN A PATIENT'S BODY



(57) Abstract: The present invention relates to a medical imaging system for guiding a medical instrument (4) which performs a plurality of actions at a plurality of points (P_1, P_2, ...P_M) in contact with a structure (3) of a body of a subject. Such a medical imaging system comprises acquisition means for acquiring a plurality of three-dimensional (3D) image data sets (3DIS(t_1), 3DIS(t_2)...3DIS(t)) of said structure (3), means (9) for associating one of said plurality of points (P_j) with one of said plurality of 3D image data sets (3DIS(t_i)), means (10) for computing a reference 2D image data set (3DIS(t_R)) from said plurality of 3D image data sets, means (11) for defining a transformation (TR(t_i)) to the points (P_j) of said plurality of points which are associated with said one of said 3D image data sets (3DIS(t_i)) and means (13) for visualizing said transformed points (TR(ti)Pj).

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A MEDICAL IMAGING SYSTEM FOR MAPPING A STRUCTURE IN A PATIENT'S BODY

FIELD OF THE INVENTION

The present invention relates to a medical imaging system for mapping a structure of a patient's body using a medical instrument and three-dimensional imaging. The present invention also relates to a method to be used in said medical imaging system.

Such an invention is used for guiding the placement and operation of an invasive medical instrument in a body organ, in particular the heart.

BACKGROUND OF THE INVENTION

Clinical applications in which an invasive medical instrument has to be guided into the body of a patient are becoming widespread. Notably the growing interest in minimally invasive methods for the treatment of cardiac diseases necessitates the development of methods and devices allowing the physician to guide a medical instrument to predetermined positions inside or outside the heart. In electrophysiology for example, it is necessary to guide a catheter to a plurality of positions on the ventricular or atrial walls in order to measure an electrical pulse or to burn wall tissues.

A method and system for mapping a structure in the body of a patient is disclosed in the European Patent Application published with publication number EP1182619A2. A three-dimensional image data set of the structure is captured. A 3D geometrical map of the structure is generated using a medical intrument inserted into the structure in the following way: the medical instrument, which is equipped with a position sensor, is brought into contact with the structure at a multiplicity of locations on the structure, which are recorded on the 3D geometrical map. The 3D image data set is registered with the map, such that each of a plurality of image points in the 3D image data set is associated with a corresponding point in the 3D geometrical map. The 3D geometrical map is displayed such that diagnostic information directly coming or derived from the 3D image data set, for example related to blood flow in the structure, is displayed at the corresponding map point.

Such a method provides a solution for generating a 3D geometrical frame model of the structure from the locations provided by the medical instrument, in which the diagnostic information provided by the 3D image data set could be mapped. The locations of the medical instrument have to be chosen such that a geometrical shape of the structure can be built up. Based on the combined diagnostic and geometrical information, a user operating the catheter is able to identify and visualize areas of the structure, for example the heart, that are

in need of treatment. A drawback of such a method is that it does not take into account the fact that the structure may have moved between two successive measurements of the medical instrument. Therefore, the obtained 3D map is not accurate.

SUMMARY OF THE INVENTION

It is an object of the invention to provide a system which generates a 3D map of a structure of a patient's body, which is more accurate.

This is achieved by a medical imaging system comprising:

- acquisition means for acquiring a plurality of three-dimensional (3D) image data sets of a structure of a body of a subject,
- a medical instrument for performing a plurality of actions at a plurality of points in contact with said structure,
- means for associating one of said plurality of points with one of said plurality of 3D image data sets,
- means for computing a reference 3D image data set from said plurality of 3D image data sets,
- means for defining a transformation for matching said one of said plurality of 3D image data sets with said reference 3D image data set,
- means for applying said matching transformation to the points of said plurality of points which are associated with said one of said 3D image data sets,
- means for visualizing said transformed points.

With the invention, the structure of the body, for instance a heart cavity, is explored from the inside using the medical instrument placed inside the structure, and from the outside using the 3D image acquisition means.

The acquisition means are adapted to successively acquire a plurality of 3D image data sets of said structure, for example 3D ultrasound image data sets using an ultrasound probe. It should be noted that imaging modalities other than ultrasound, such as CT or X-ray, may be used as well. An advantage of ultrasound imaging is that it shows the structure wall and vascularities. An advantage of acquiring a plurality of 3D image data sets is that they show an evolution of the structure in time. As a matter of fact, a structure of the body like, for instance, the heart is expected to move and change shape due to contractions during the cardiac cycle.

The medical instrument is adapted to perform a plurality of actions, for instance measuring an electrical activity or burning a tissue at a plurality of location points of the structure wall with which it is brought into contact. In the first case, the objective is to completely and uniformly map the structure wall. In the second case, the objective is to precisely reach desired points of the structure wall. These actions are performed successively by the medical instrument within a certain period of time.

The associating means are intended to associate a point with a 3D image data set. Advantageously, a point corresponding to an action performed at time t is associated with a 3D image data set acquired at the same time instant or at a time instant which is very close to time t. An advantage is that the associated 3D image data set provides information about the background of the structure at the instant when the action has been performed by the medical instrument.

The means for computing a reference 3D image data set from said plurality of 3D image data sets are intended to derive a reference 3D image data set, for instance, from a combination of the last two acquired 3D image data sets. Said reference 3D image data set can simply be chosen as a 3D image data set from the plurality of 3D image data sets as well.

For each 3D image data set, which has been associated with at least one point, a transformation is defined for matching said 3D image data set with said reference image data set. Such an operation is repeated for the points which are associated with another 3D image data set, using another transformation. In this way, these transformed points are registered with respect to the reference 3D image data set.

The visualization means are then adapted to provide a visualization of the transformed points, thereby forming a map of the structure. Such a map comprises at each action point a result of the action performed, for example, a measure or an indication that the tissue has been burnt.

Therefore, the map obtained with the invention is more accurate, because an adapted transformation has been applied to each point, which compensates for any deformation or motion undergone by the structure in the time between the acquisition of the reference image data set and the acquisition of the associated 3D image data set.

Advantageously, the means for visualizing said transformed points comprise sub-means for generating a representation, in which the transformed points are superimposed either with the reference 3D image data set or with the current 3D image data set acquired at time t after transformation by the matching transformation defined for the current 3D image data set. A first advantage is that such a superimposition may help the user to place the action points in

relation to the surrounding anatomy. Another advantage is that said representation may help the user to decide where to perform a next action.

In a first embodiment of the invention, the reference image data set is chosen as a fixed 3D image data set, for instance acquired at a time t_1. In other words, a fixed map is generated and each new point is registered with respect to said fixed reference. An advantage is that reading of the map is facilitated because, when a new point appears on the map, the points which have been previously processed remain unchanged.

In a second embodiment of the invention, the reference image data set is chosen as a current 3D image data set acquired at a current time t. In this case, an up-to-date map is obtained, which moves with the structure. An advantage is that at the current time t the visualized map corresponds to the real state of the structure in the body. The generated map is also more realistic, because it moves with the structure.

In a third embodiment of the invention, a geometrical transformation is applied to the reference 3D image data set. The objective is for example to ensure that the structure and consequently the map is visualized in a given orientation, which is familiar to the user. An advantage is that such a geometrically transformed map can be more easily interpreted by the user.

In a fourth embodiment of the invention, the visualization means are adapted to provide a view of a region of interest of the medical instrument. A first advantage of this fourth embodiment of the invention is that it provides a zoom-in of the vicinity of the medical instrument, which improves the visualization of the region of interest. A second advantage is that such a view provides another perspective of the structure. Therefore, combined with the representation, such a view may help the user to define a next location for performing an action with the medical instrument in a quicker and more efficient way.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in more detail, by way of example, with reference to the accompanying drawings, wherein:

- Fig. 1 is a schematic drawing of a system in accordance with the invention,
- Fig. 2 is a schematic drawing of the association means in accordance with the invention,

- Fig. 3 is a schematic drawing of the means for localizing a 3D image data set in accordance with the invention,
- Fig. 4 is a schematic drawing of the means for defining a transformation in accordance with the invention,
- Fig. 5 is a schematic drawing of the means for applying the transformation defined for a 3D image data set to the points associated with said 3D image data set in accordance with the invention,
- Fig. 6 is a schematic drawing of a map provided by the visualization means in accordance with the invention,
- Fig. 7 is a schematic drawing of a representation in which the transformed points are superimposed with the reference 3D image data set in accordance with a first embodiment of the invention,
- Fig. 8 is a schematic drawing of a representation in which the transformed points are superimposed with the reference 3D image data set in accordance with a second embodiment of the invention,
- Fig. 9 is a schematic drawing of the means for applying a geometrical transformation to the reference 3D image data set in accordance with a third embodiment of the invention,
- Fig. 10 is a schematic drawing of a view of a region of interest of the medical instrument provided by the visualization means in accordance with a fourth embodiment of the invention,
- Fig. 11 is a schematic representation of a method in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to a system for mapping a structure of a patient's body using a medical instrument and three-dimensional imaging. In the following, the system in accordance with the invention will be described in more detail by means of, in this case, the application of an electrophysiology catheter introduced into a heart cavity, for instance the left ventricular or the right atrium chamber, in order to measure an electrical activity of the heart or to burn diseased tissues.

However, the invention is not limited to electrophysiology procedures and can more generally be used for guiding any other medical instrument in the patient's body, like for instance a needle.

The schematic drawing of Fig. 1 shows a patient 1, who is arranged on a patient table 2 and whose symbolically indicated heart 3 is subjected to a treatment by means of a catheter

4 introduced into the body. The system in accordance with the invention comprises means 5 for acquiring a plurality of 3D image data sets of the structure $3DIS(t_1)$, $3DIS(t_2)$,...,$3DIS(t)$. In the following, the plurality of 3D image data sets is a plurality of ultrasound image data sets acquired from an ultrasound probe 6, which has been placed on the patient's body and fixed by fixation means, for instance a belt 7 or a stereotactic arm. It should be noted however that the invention is not limited to ultrasound acquisition means and that CT, MRI or X-Ray acquisition means could be used as well.

Advantageously, the 3D acquisition means 5 are adapted to provide a live 3D image data set. For instance, the 3D image data sets $3DIS(t_1)$, $3DIS(t_2)$,...,$3DIS(t)$ are acquired at predetermined phases of the cardiac cycle. It should be noted however that they can be acquired at any phase of the cardiac cycle as well.

The plurality of 3D image data sets is stored in a memory 6.

The system in accordance with the invention comprises a medical instrument 4 to be guided inside the structure 3 for performing a plurality of actions at a plurality of location points $P_1, P_2, \ldots, P_M$, where M is an integer, in contact with said structure. Said plurality of actions is controlled by a controller 8 and the results of this plurality of actions are stored in a memory 8.

The system in accordance with the invention further comprises means 9 for associating one of said plurality of points P_j with one of said plurality of 3D image data sets $3DIS(t_i)$, means 10 for computing a reference 3D image data set $3DIS(t_R)$ from said plurality of 3D image data sets, means 11 for defining a transformation $TR(t_i)$ for matching said one of said plurality of 3D image data sets $3DIS(t_i)$ with the reference 3D image data set $3DIS(t_R)$, means 12 for applying said matching transformation $TR(t_i)$ to the points P_j of said plurality of points which are associated with said one of said 3D image data sets $3DIS(t_i)$ and means 13 for visualizing said transformed points $TR(t_i)Pj$ using display means 14.

In acordance with the invention, the medical instrument 4 has an extremity, which is adapted to perform an action A_j, such as measuring an electrical activity or burning a tissue, when it is brought into contact with a location point P_j of the inside wall of the structure. In the particular case of an electrophysiology procedure, this extremity of the catheter 4 is called a tip. Advantageously, the controller 8 comprises sub-means for localizing the tip of the catheter, which give the precise location of the location point contacted by the medical instrument. In a first alternative, the medical instrument 4 is equipped with an active localizer, for instance an RF coil, as described above for localizing the ultrasound probe 6. Said tip is a small and thin segment, which is very echogenic and leaves a specific signature

in the 3D ultrasound image data set. In a second alternative, the tip localization sub-means advantageously employ image processing techniques, which are well known to those skilled in the art, for enhancing either a highly contrasted blob or an elongated shape in a relatively uniform background.

Therefore, the tip localization sub-means are adapted to provide a location of a contact point $P_j=(x_j, y_j, z_j)$ of the medical instrument 4 and the inside wall of the structure 3 at a time t_j. In the first alternative, such a location is directly expressed in a fixed referential, for instance a referential (O, x, y, z) of the clinical intervention room. In the second alternative, it is firstly expressed in a local referential (O', x', y', z') of the ultrasound probe 6 and converted into coordinates within the referential of the clinical intervention room (O, x, y, z) by conversion means, well-known to those skilled in the art.

The system comprises means 9 for associating a location point P_j, j being an integer, with one 3D image data set from the plurality of 3D image data sets $3DIS(t_1)$, $3DIS(t_2)$,...,$3DIS(t)$. Advantageously, the location point P_j, which corresponds to an action A_j performed at a time instant t_j, is associated with the 3D image data set $3DIS(t_i)$ acquired at time t_i, said time being the closest time to t_j among the times of acquisition of the 3D image data sets $3DIS(t_1)$ to $3DIS(t)$.

Referring to Fig. 2, the location points P_1, P_2 are therefore associated with the 3D image data set $3DIS(t_1)$, the location point P_3 with the 3D image data set $3DIS(t_2)$, the location points P_4, P_5 with the 3D image data set $3DIS(t_3)$ and the location point P_6 with the 3D image data set $3DIS(t_4)$.

An advantage is that the associated 3D image data set $3DIS(t_i)$ can be considered to represent a state of the structure 3 at the instant t_j at which the action was performed at the location point P_j. It should be noted that more than one location may be associated with one 3D image data set.

The means 10 are intended to derive a reference 3D image data set $3DIS(t_R)$. For instance, the reference 3D image data set $3DIS(t_R)$ is built up by combining the last two acquired 3D image data sets 3DIS(t-1) and 3DIS(t), especially if there is a location point acquired at a time close to t-1/2. Said reference 3D image data set can also simply be chosen as a 3D image data set from the plurality of 3D image data sets, for instance as the first 3D image data set $3DIS(t_1)$ acquired at a time t_1 or the current 3D image data set 3DIS(t) acquired at a time t. In the following, it is assumed that the reference 3D image data set $3DIS(t_R)$ has been acquired at a time tR, where R is an integer that is a priori different from i. Between time t_R and time t_i, both the ultrasound probe 6 and the structure 3 may have moved.

Referring to Fig. 3, the system further comprises means 11 for defining a transformation $TR(t_i)$ which matches the 3D image data set $3DIS(t_i)$ with the reference 3D image data set $3DIS(t_R)$ in the fixed referential (O, x, y, z) of the clinical intervention room.

Referring to Fig. 3, the system in accordance with the invention advantageously comprises means for localizing the ultrasound probe 6 in a fixed referential of coordinates with respect to the ultrasound probe, for instance the referential of coordinates (O, x, y, z) of the clinical intervention room.

Such a localization is for instance based on an active localizer, well-known to those skilled in the art, which is arranged on the ultrasound probe 6. Said active localizer, for instance an RF coil, is intended to transmit an RF signal to an RF receiving unit placed under the patient's body and for instance integrated into the table 2. The RF receiving unit transmits the received signal to measuring means for measuring a position of the ultrasound probe 6 in the referential (O, x, y, z) of the clinical intervention room. It should be noted that the active localizer must provide a precise measurement of the position and of the orientation of the ultrasound probe 6. It should further be noted that a led-based optical localizer could be used as well. A first advantage of such a localization is that it is very precise. A second advantage is that it is performed in real-time and therefore can be triggered during the clinical procedure, if necessary.

As already mentioned, the ultrasound probe 6 is likely to move during the clinical intervention due to external movements of the patient, such as respiratory movements. Therefore, means for localizing the ultrasound probe 6 are intended to provide a localization of the ultrasound probe 6 at a time t_i, which simultaneously gives a localization of the 3D image data set acquired at time t_i in the referential of coordinates (O, x, y, z). Such a localization completely defines a position and orientation of the ultrasound probe 6 and the 3D image data set $3DIS(t_i)$ within the referential (O, x, y, z) and for instance comprises the coordinates of a point O' and of three orthogonal vectors $\overrightarrow{O'X'}$, $\overrightarrow{O'Y'}$, $\overrightarrow{O'Z'}$.

Advantageously, a local referential of coordinates (O', x', y', z')(t) is attached to the ultrasound probe 6 at time t. Such a referential (O', x', y', z')(t) is particularly useful in order to localize structures of interest in the 3D image data set, such as the medical instrument 4 or the structure 3. Such a local referential moves with the 3D image data set. Therefore, a localization $Loc(t_i)$ of the local referential (O', x', y', z')(t_i) attached to the 3D image data set $3DIS(t_i)$ and a localization $Loc(t_R)$ of the local referential (O', x', y', z')(t_R) attached to the reference 3D image data set $3DIS(t_R)$ are provided within the referential (0, x, y, z) of the clinical intervention room. Consequently, a first transformation $Tr(t_i)$, which matches the

localizations $Loc(t_i)$ and $Loc(t_R)$ can be defined within the referential (O, x, y, z) by the means 11 for defining a transformation.

Advantageously, the means 11 for defining a transformation $TR(t_i)$, which matches the 3D image data set $3DIS(t_i)$ with the reference image data set $3DIS(t_R)$, comprises sub-means for segmenting the structure 3 both within the local referentials (O, x', y', z')(t_i) and (O, x', y', z')(t_R) of the ultrasound probe 6.

Referring to Fig. 4, said sub-means are adapted to segment a first surface $S1(t_i)$ of said structure in the 3D image data set $3DIS(t_i)$ and a second surface $S_1(t_R)$ of said structure in the reference 3D image data set $3DIS(t_R)$. Given a set of points of said first surface $S_1(t_i)$, a corresponding second set of points may be searched for use in the reference 3D image data set $3DIS(t_R)$ using, for instance, an Iterative Closest Point Algorithm, well known to those skilled in the art. The means for defining a transformation $TR(t_i)$ are adapted to seek a second transformation $Tr'(t_i)$, for instance from a family of transformations, that minimizes a mean square error between the first and second sets of points $S_1(t_i)$, $S_1(t_R)$. Advantageously, additional features like curvature measurements $C_1(t_i)$, $C_1(t_R)$ may be used to improve the matching. The second transformation $Tr'(t_i)$ is then applied to all the points of the first surface $S_1(t_i)$.

It should be noted that the medical instrument 4 must not interfere in such a process of finding a matching transformation, since the medical instrument may have moved with respect to the structure 3.

Therefore, referring to Fig. 4, the transformation $TR(t_i)$ may be decomposed into a first transformation $Tr(t_i)$, which matches the localization $Loc(t_i)$ of the local referential (O', x', y', z')(t_i) of the ultrasound probe 6 within the referential (O, x, y, z) at time t_i with the localization $Loc(t_R)$ of the local referential (O', x', y', z')(t_R) of the ultrasound probe 6 at time t_R, and into a second transformation $Tr'(t_i)$, which matches the structure 3 within the 3D image data set $3DIS(t_i)$ with the structure 3 within the reference 3D image data set $3DIS(t_R)$.

In this way, an adapted transformation $TR(t_i)$ is defined for each 3D image data set $3DIS(t_i)$ which has location points P_j associated with. Therefore, a plurality of transformations is defined during the clinical intervention.

Referring to Fig. 5, the defined transformation $TR(t_i)$ is then applied by means 12 to the location point(s) P_j associated with the 3D image data set $3DIS(t_i)$. In this way, a transformed location point $TR(t_i)Pj$ is obtained, which is registered with respect to the reference image data set $3DIS(t_R)$.

The system in accordance with the invention finally comprises means 13 for visualizing the plurality of transformed location points $TR(t_i)Pj$, obtained by applying said plurality of transformations.

Referring to Fig. 6, the plurality of transformed location points forms a map M of the structure 3 in which the result of the action A_j, for example a measurement value or an indication that the tissue has been burnt, is given at each transformed location point $TR(t_i)P_j$. Said map is registered with respect to the reference 3D image data set $3DIS(t_R)$, because the plurality of location points $P_1, P_2,\ldots, P_M$ which constitutes this map has been registered by adapted transformations with respect to this reference image data set.

The map M is displayed by display means 14.

In a first embodiment of the invention, shown in Fig. 7, the reference 3D image data set $TR(t_i)P_j$ is a fixed 3D image data set, for example the first 3D image data set $3DIS(t_1)$ acquired at time t_1. Therefore, a location point P_j associated with a 3D image data set $3DIS(t_i)$ is firstly transformed into a transformed point $TR(t_i)Pj$ by the transformation $TR(t_i)$, which matches the 3D image data set $3DIS(t_i)$ with the reference 3D image data set $3DIS(t_R)$, and then visualized by the visualization means 13.

In a first alternative, the means 13 for visualizing said transformed points comprise sub-means for generating a representation R, in which said transformed points $TR(t_i)P_j$ are superimposed with said reference 3D image data set $3DIS(t_R)$, as shown in Fig. 7.

Therefore, the representation R provided by the visualization means 13 comprises a fixed anatomical background on which the transformed location points $TR(t_i)P_j$ are successively superimposed. It should be noted that, as shown in Fig. 7, the position of the medical instrument is a priori not updated.

Advantageously, the system further comprises means for excluding the medical instrument 4 from the reference 3D image data set, for instance by using detection means based on image processing techniques which are well-known to those skilled in the art.

A first advantage of such a representation is that it is obtained in a simple way, because a single transformation $TR(t_i)$ is applied to each location point P_j. A second advantage is that reading of the representation is facilitated because, when a new location point appears on the representation R, the points which have been previously processed remain unchanged.

In a second alternative, the medical imaging system in accordance with the invention further comprises means for applying said transformation $TR(t_i)$ to the 3D image data set

$3DIS(t_i)$. A transformed 3D image data set $TR(t_i)3DIS(t_i)$ is obtained, which is used to generate the representation $R(t_i)$ at time t_i. Therefore, at time t_i the representation $R(t_i)$ shows the currently transformed location points $TR(t_i)Pj$ and the previously transformed points superimposed with the 3D image data set $TR(t_i)(3DIS(t_i))$. A first advantage is that in the representation R both the medical instrument 4 and the structure 3 are updated. Therefore, the anatomical background formed by the image data is up to date. Moreover, by applying the transformation $TR(t_i)$ to the 3D image data set $3DIS(t_i)$, compensation is provided for any motion of the structure 3 with respect to the reference 3D image data set $3DIS(t_R)$. Consequently, a second advantage is that the guiding of the medical instrument to a next target point is facilitated.

In a second embodiment of the invention, shown in Fig. 8, the reference image data set $3DIS_{(}t_R)$ is chosen as a 3D image data set acquired at a current time t, for example, as the current 3D image data set. In this case, an up-to-date representation R(t) is obtained, which moves with the structure 3. In this case, a new location point P_j associated with the 3D image data set 3DIS(t) is superimposed without any transformation to the reference 3D image data set $3DIS_R(t)$, because it corresponds to the current 3D image data set with which it is associated. In this case, all the previously acquired location points which have been superimposed to the previous reference 3D image data set 3DIS(t-1) in order to form the representation R(t-1) at time t-1 need to be registered with respect to the reference 3D image data set 3DIS(t) at time t so that the representation can be updated.

In a first alternative, referring to Fig. 8, the previously acquired location points superimposed with the previous reference 3D image data set 3DIS(t-1) are all transformed, by an identical update transformation $TR_{up}(t)$ which matches the reference 3D image data set 3DIS(t-1) at time t-1 with the reference 3D image data set 3DIS(t) at time t, into transformed points $TR_{up}(t)P_1$, $TR_{up}(t)P_2$, $TR_{up}(t)P_3$, $TR_{up}(t)P_4$ and $TR_{up}(t)P_5$.

Consequently, in accordance with the second embodiment of the invention, a location point P_j acquired at time t_j is transformed by a global transformation $TR(t_i)$, which comprises a succession of successive update transformations TR_{up} at times t-1, t, t+1. Therefore, at time t, the point Pj acquired at time t-1 is transformed into a transformed point $Tr_{up}(t)Pj$, which is further transformed at time t+1 by an update transformation $TR_{up}(t+1)$ etc.

A first advantage is that at the current time t the visualized representation R(t) corresponds to the live state of the structure in the body. The generated map of the location

points is also more realistic. A second advantage is that the computation needs are reasonable.

In a second alternative, a location point P_j acquired at time t_j and associated with the 3D image data set $3DIS(t_i)$ is successively transformed by a plurality of transformations $TR_i(t_{j+1})$, ..., $TR_i(t)$. The location point P_j is transformed at time t into a transformed point $TR_i(t)P_j$ by a transformation $TR_i(t)$, which registers the 3D image data set $3DIS(t_i)$ with the reference 3D image data set $3DIS(t)$; the same location point P_j is further transformed at time t+1 into a transformed point $TR_i(t+1)P_j$ by a transformation $TR_i(t+1)$ which registers the 3D image data set $3DIS(t_i)$ with the reference 3D image data set $3DIS(t+1)$ etc. An advantage is that errors due to successive transformations do not accumulate.

In a third embodiment of the invention, the reference image data set $3DIS(t_R)$ is transformed by a geometrical transformation. The objective of such a geometrical transformation is for example to ensure that the structure and consequently the representation is visualized by the user in a way he is familiar with. For example, such a geometrical transformation may place the structure in the center of the 3D image data set or put it in a desired orientation. Referring to Fig. 9, an orientation axis OA of the structure 3 may be detected in the reference 3D image data set $3DIS(t_R)$ by using image processing techniques known to those skilled in the art. A geometrical transformation GT is then defined, which, when applied to the structure 3, will place it in the desired position and orientation. Such a geometrical transformation has to be applied to the transformed location points before superimposing them to the reference 3D image data set $3DIS(t_R)$. An advantage is that such a geometrically transformed representation can be more easily interpreted by the user.

In a fourth embodiment of the invention, the visualization means 12 are adapted to provide a view of a region of interest of the medical instrument 4. Referring to Figs 10A and 10B, such a view is for instance generated by choosing a plane Pl in the reference 3D image data set $3DIS_R$, which contains the tip of the medical instrument 4 and which is perpendicular to the medical instrument. This is achieved by defining a slab Sb of the 3D image data set centered on this plane Pl. The visualization means 12 may advantageously comprise sub-means for generating a 3D rendered view of this slab on which the transformed location points corresponding to this region of interest are superimposed. A first advantage of this fourth embodiment of the invention is the possibility to provide a zoom-in of the vicinity of the medical instrument 4, which improves the visualization of the region of interest. A second advantage is that such a view provides another perspective of the structure 3. Therefore,

combined with the representation, such a view may help the user to define a next location for performing an action with the medical instrument 4 in a quicker and more efficient way. In particular, the vicinity of the entrance of the pulmonary vein in the left atrium is a region of great interest, because it plays a role in heart diseases which require burning tissues in this region of interest. Referring to Figs 10A and 10B, a view of the vicinity of the pulmonary vein is very likely to help the user decide on a next location for performing an action with the medical instrument.

The invention also relates to a method of mapping a structure of a patient's body using a medical instrument and three-dimensional imaging. Referring to Fig. 11, such a method comprises the steps of:

- acquiring 20 a plurality of three-dimensional (3D) image data sets $3DIS(t_1)$, $3DIS(t_2)$, ..., $3DIS(t)$ of a structure 3 of a body of a subject,
- performing 21 a plurality of actions at a plurality of points $P_1, P_2, \ldots P_M$ in contact with said structure,
- associating 22 one of said plurality of points P_j with one of said plurality of 3D image data sets $3DIS(t_1)$, $3DIS(t_2)$, ..., $3DIS(t)$,
- computing 23 a reference 3D image data set ($3DIS(t_R)$) from said plurality of 3D image data sets ($3DIS(t_1)$, $3DIS(t_2)\ldots 3DIS(t)$),
- defining 24 a transformation $TR(t_i)$ for matching one of said plurality of 3D image data sets $3DIS(t_i)$ with a reference 3D image data set $3DIS(t_R)$ comprised within said plurality of 3D image data sets,
- applying 25 said matching transformation $TR(t_i)$ to the points P_j of said plurality of points $P_1, P_2, \ldots P_M$ which are associated with said one of said 3D image data sets $3DIS(t_i)$,
- visualizing 26 said transformed points $TR(t_i)Pj$.

The drawings and their description hereinbefore illustrate rather than limit the invention. It will be evident that there are numerous alternatives, which fall within the scope of the appended claims. In this respect the following closing remarks are made: there are numerous ways of implementing functions by means of items of hardware or software, or both. In this respect, the drawings are very diagrammatic, each representing only one possible embodiment of the invention. Thus, although a drawing shows different functions as different blocks, this by no means excludes that a single item of hardware or software carries out

several functions, nor does it exclude that a single function is carried out by an assembly of items of hardware or software, or both.

Any reference sign in a claim should not be construed as limiting the claim. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. Use of the article "a" or "an" preceding an element or step does not exclude the presence of a plurality of such elements or steps.

CLAIMS

1. A medical imaging system comprising:
- acquisition means (5) for acquiring a plurality of three-dimensional (3D) image data sets ($3DIS(t_1)$, $3DIS(t_2)...3DIS(t)$) of a structure (3) of a body of a subject at times t_1, $t_2...t$,
- a medical instrument (4) for performing a plurality of actions at a plurality of points (P_1, P_2, ...P_M) in contact with said structure,
- means (9) for associating one of said plurality of points (P_j) with one of said plurality of 3D image data sets ($3DIS(t_i)$),
- means (10) for computing a reference 3D image data set ($3DIS(t_R)$) from said plurality of 3D image data sets ($3DIS(t_1)$, $3DIS(t_2)...3DIS(t)$),
- means (11) for defining a transformation ($TR(t_i)$) for matching said one of said plurality of 3D image data sets ($3DIS(t_i)$) with said reference 3D image data set ($3DIS(t_R)$),
- means (12) for applying said matching transformation ($TR(t_i)$) to the points (P_j) of said plurality of points which are associated with said one of said plurality of said 3D image data sets ($3DIS(t_i)$),
- means (13) for visualizing said transformed points ($TR(t_i)Pj$).

2. A medical imaging system as claimed in claim 1, wherein said reference image data set ($3DIS(t_R)$ is a fixed 3D image data set ($3DIS(t_1)$).

3. A medical imaging system as claimed in claim 1, wherein said reference image data set ($3DIS(t_R)$) is a current 3D image data set ($3DIS(t)$).

4. A medical imaging system as claimed in claim 1, wherein said means for visualizing said transformed points ($TR(t_i)Pj$) comprise sub-means for generating a representation (R), in which said transformed points are superimposed with said reference 3D image data set ($3DIS(t_R)$).

5. A medical imaging system as claimed in claim 2, comprising means for applying said current matching transformation ($TR(t)$) to said current 3D image data set ($3DIS(t)$), and wherein said means for visualizing said transformed points ($TR(t_i)Pj$) comprise sub-means for generating a representation (R), in which said transformed points are superimposed with said transformed current 3D image data set ($TR(3DIS(t))$).

6. A medical imaging system as claimed in claim 1, wherein said means for visualizing said transformed points ($TR(t_i)P_j$) comprise sub-means for generating a view of a region of interest of the medical instrument (4), which is perpendicular to a plane (Pl) comprising an extremity of said medical instrument.

7. A medical imaging system as claimed in claim 1, comprising means for localizing said plurality of location points (P_1, P_2, ...P_M) in a fixed referential of coordinates (O, x, y, z).

8. A medical imaging system as claimed in claim 1, comprising means for localizing said plurality of 3D image data sets ($3DIS(t_1)$, $3DIS(t_2)$...3DIS(t)) in a fixed referential of coordinates (O, x, y, z).

9. A medical imaging system as claimed in claim 1, wherein said reference image data set ($3DIS(t_R)$) has been subjected to a geometrical transformation (GT).

10. A medical imaging system as claimed in claim 8, wherein said transformation ($TR(t_i)$) comprises a first transformation ($Tr(t_i)$) for matching a local referential (O', x', y', z')(t_i) of said one of said plurality of 3D image data sets ($3DIS(t_i)$) with a reference local referential (O', x', y', z')(t_R) of said reference 3D image data set ($3DIS(t_R)$) within said fixed referential of coordinates (O, x, y, z), and a second transformation ($Tr'(t_i)$) for matching a location ($S1(t_i)$) of said structure (3) in said one of said plurality of 3D image data sets ($3DIS(t_i)$) with a reference location ($S1(t_R)$) of said structure in said reference 3D image data set ($3DIS(t_R)$) within said matched local referential of coordinates $Tr(t_i)$(O', x', y', z') of said 3D image data set ($3DIS(t_i)$).

11. A medical imaging system as claimed in claim 3, wherein said transformation ($TR(t_i)$) comprises successive update transformations (TR_{up}) for transforming a location of a transformed point ($Tr_{up}(t-1)P_j$) in a previous reference 3D image data set ($3DIS_R(t-1)$) acquired at time t-1 into a location $TR_{up}(t)P_j$) in the current reference 3D image data set ($3DIS_R(t)$) acquired at time t.

12. A medical imaging system as claimed in claim 3, wherein a new transformation ($TR_i(t)$) for matching said one of said plurality of 3D image data sets ($3DIS(t_i)$) with said current 3D image data set ($3DIS(t)$) is applied to said point (P_j) associated with said one of said plurality of 3D image data sets ($3DIS(t_i)$) when said reference 3D image data set ($3DIS(t_R)$) is replaced by said current 3D image data set ($3DIS(t)$).

13. A medical imaging system as claimed in claim 1, wherein said structure is a heart and said medical instrument is an electrophysiology catheter.

14. A medical imaging system as claimed in claim 1, wherein said association means (9) are adapted to associate a point (P_j) acquired at a time t_j with a 3D image data set ($3DIS(t_i)$) acquired at a time t_i which is close to time t_j.

15. A medical imaging system as claimed in claim 1, wherein said acquisition means (5) are intended to acquire a plurality of 3D ultrasound image data sets using an ultrasound probe (6) arranged on the body of the subject.

16. A medical imaging method, comprising the steps of:

- acquiring (20) a plurality of three-dimensional (3D) image data sets ($3DIS(t_1)$, $3DIS(t_2)\ldots3DIS(t)$) of a structure (3) of a body of a subject,
- performing (21) a plurality of actions at a plurality of location points (P_1, P_2, $\ldots P_M$) in contact with said structure,
- associating (22) one of said plurality of points (P_j) with one of said plurality of 3D image data sets ($3DIS(t_i)$),
- computing (23) a reference 3D image data set ($3DIS(t_R)$) from said plurality of 3D image data sets ($3DIS(t_1)$, $3DIS(t_2)\ldots3DIS(t)$),
- defining (24) a transformation ($TR(t_i)$) for matching one of said plurality of 3D image data sets with said reference 3D image data set ($3DIS(t_R)$),
- applying (25) said matching transformation ($TR(t_i)$) to the location points of said plurality of location points which are associated with said one of said plurality of 3D image data sets,
- visualizing (26) said transformed points ($TR(t_i)P_j$).

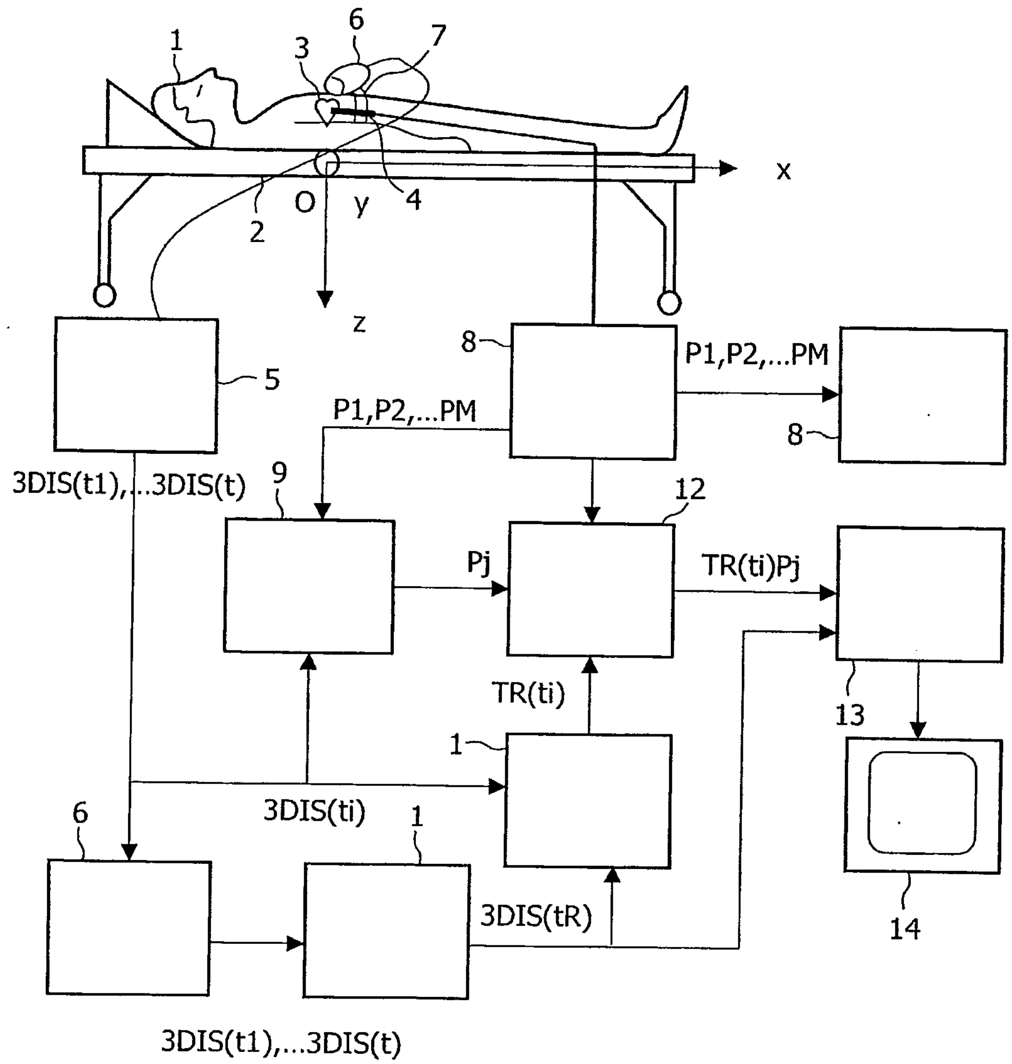

1
3
6
7
x
O
y
4
2
z
5
8
P1,P2,...PM
P1,P2,...PM
8
3DIS(t1),...3DIS(t)
9
12
Pj
TR(ti)Pj
TR(ti)
13
1
3DIS(ti)
6
1
3DIS(tR)
14
3DIS(t1),...3DIS(t)

FIG.1

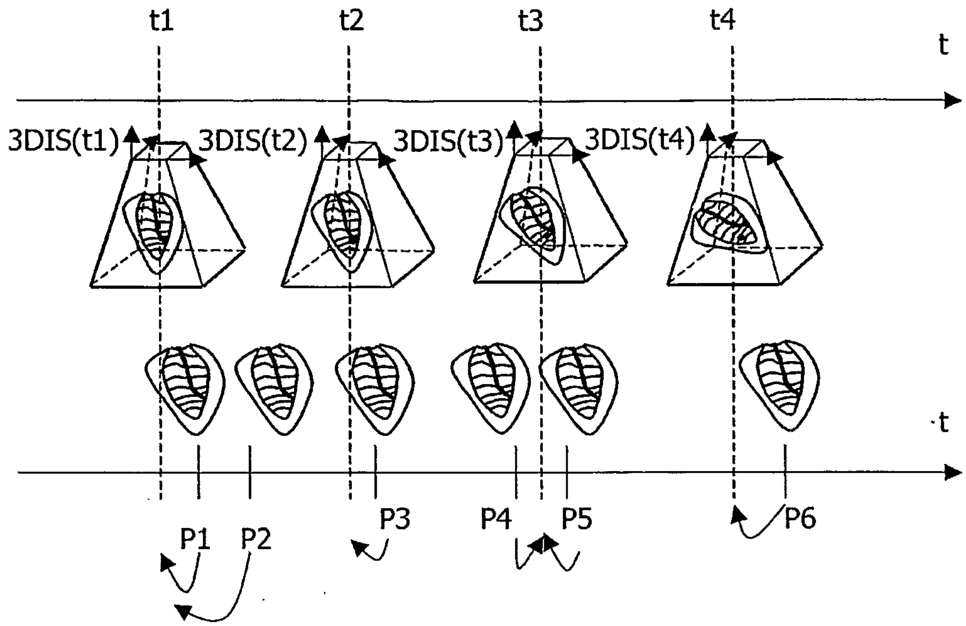


FIG.2

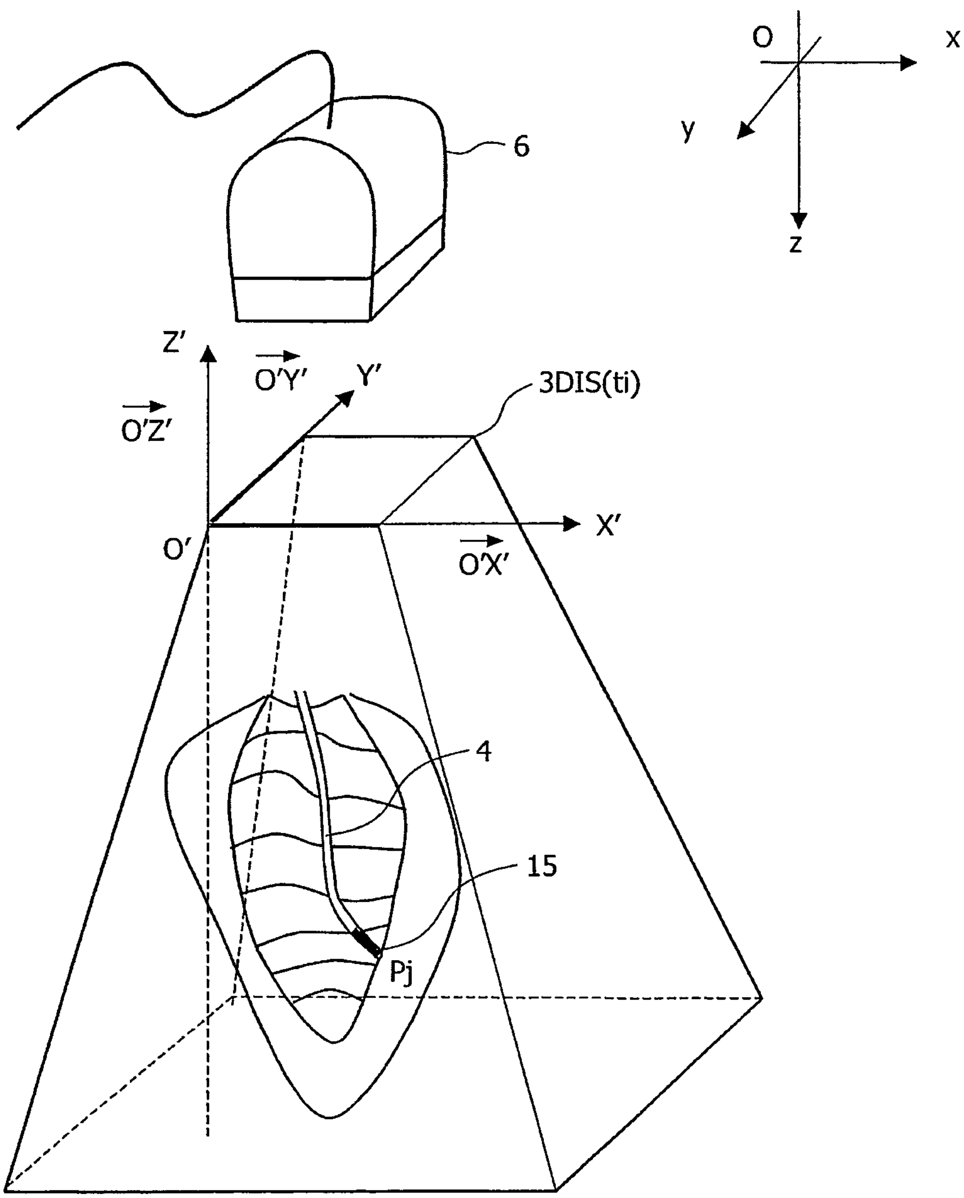


FIG.3

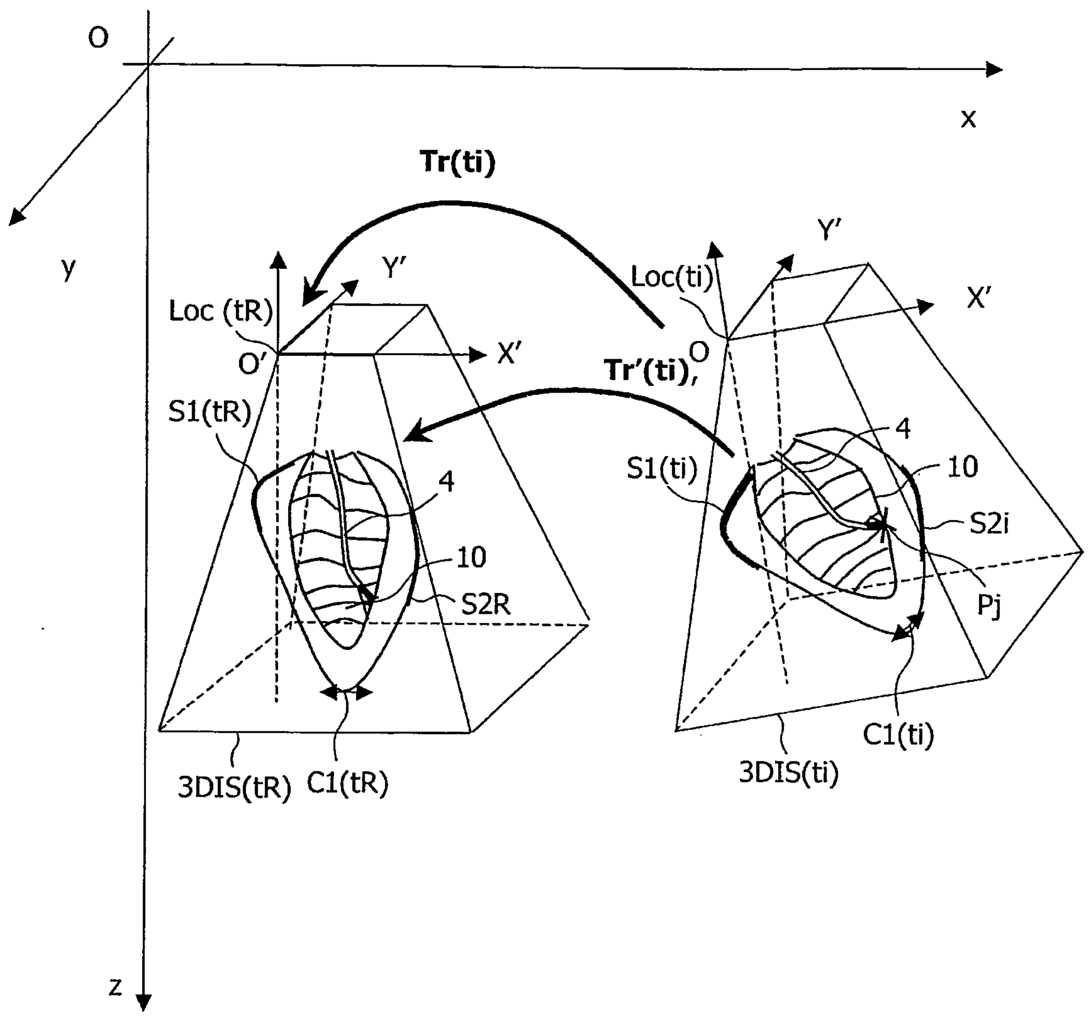

O
x
y
z
Tr(ti)
Tr'(ti)
Loc (tR)
O'
Y'
X'
S1(tR)
4
10
S2R
3DIS(tR)
C1(tR)
Loc(ti)
O
Y'
X'
S1(ti)
4
10
S2i
Pj
C1(ti)
3DIS(ti)

FIG.4

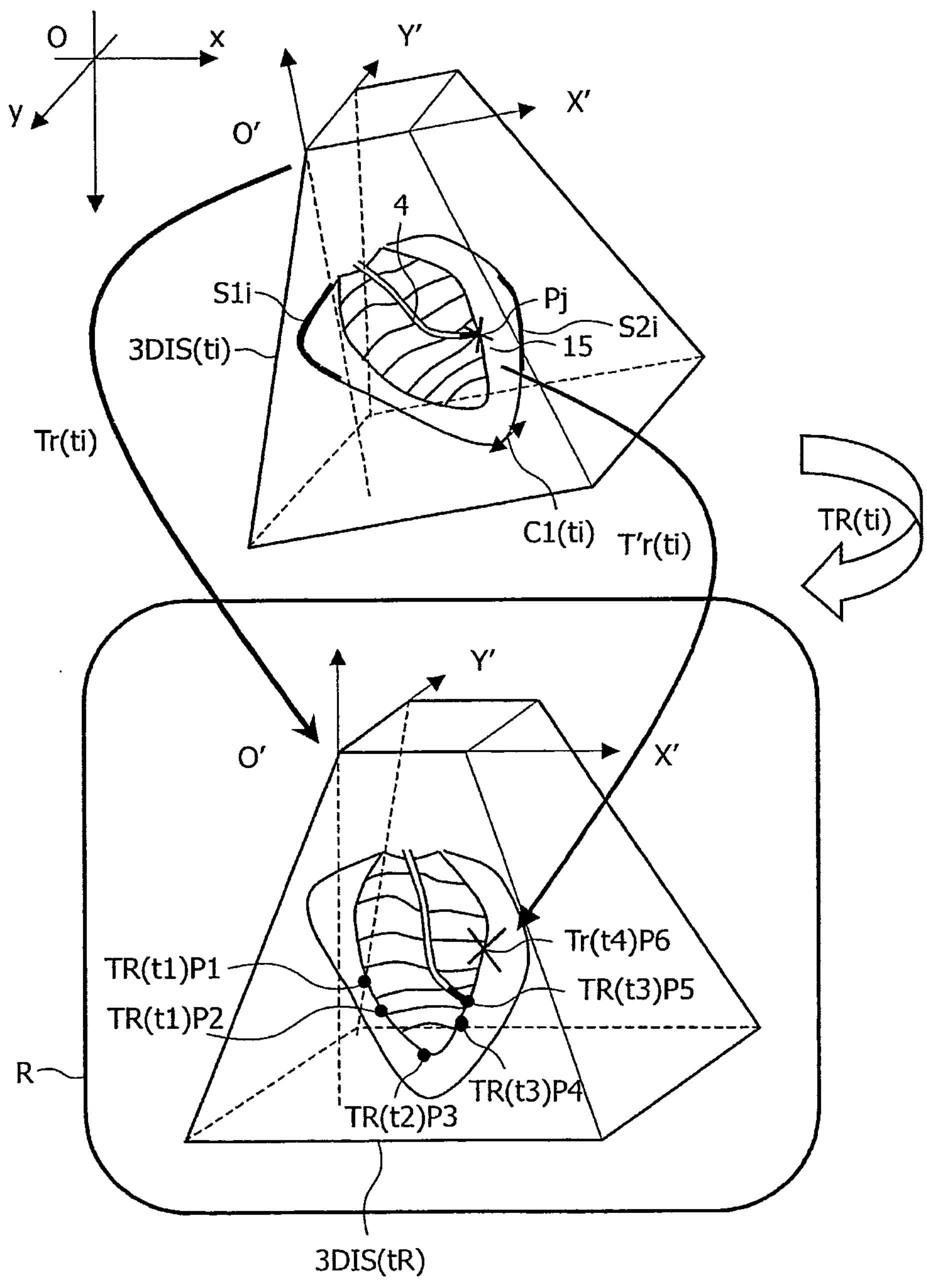

O
x
y
Y'
X'
O'
4
S1i
Pj
S2i
15
3DIS(ti)
Tr(ti)
C1(ti)
T'r(ti)
TR(ti)
Y'
O'
X'
Tr(t4)P6
TR(t1)P1
TR(t3)P5
TR(t1)P2
R
TR(t3)P4
TR(t2)P3
3DIS(tR)

FIG.5

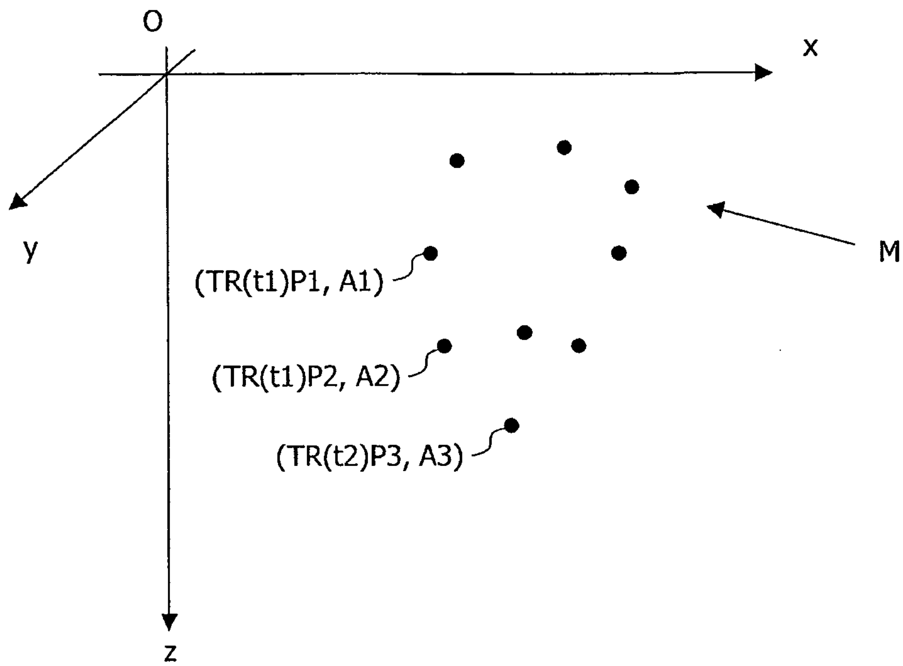
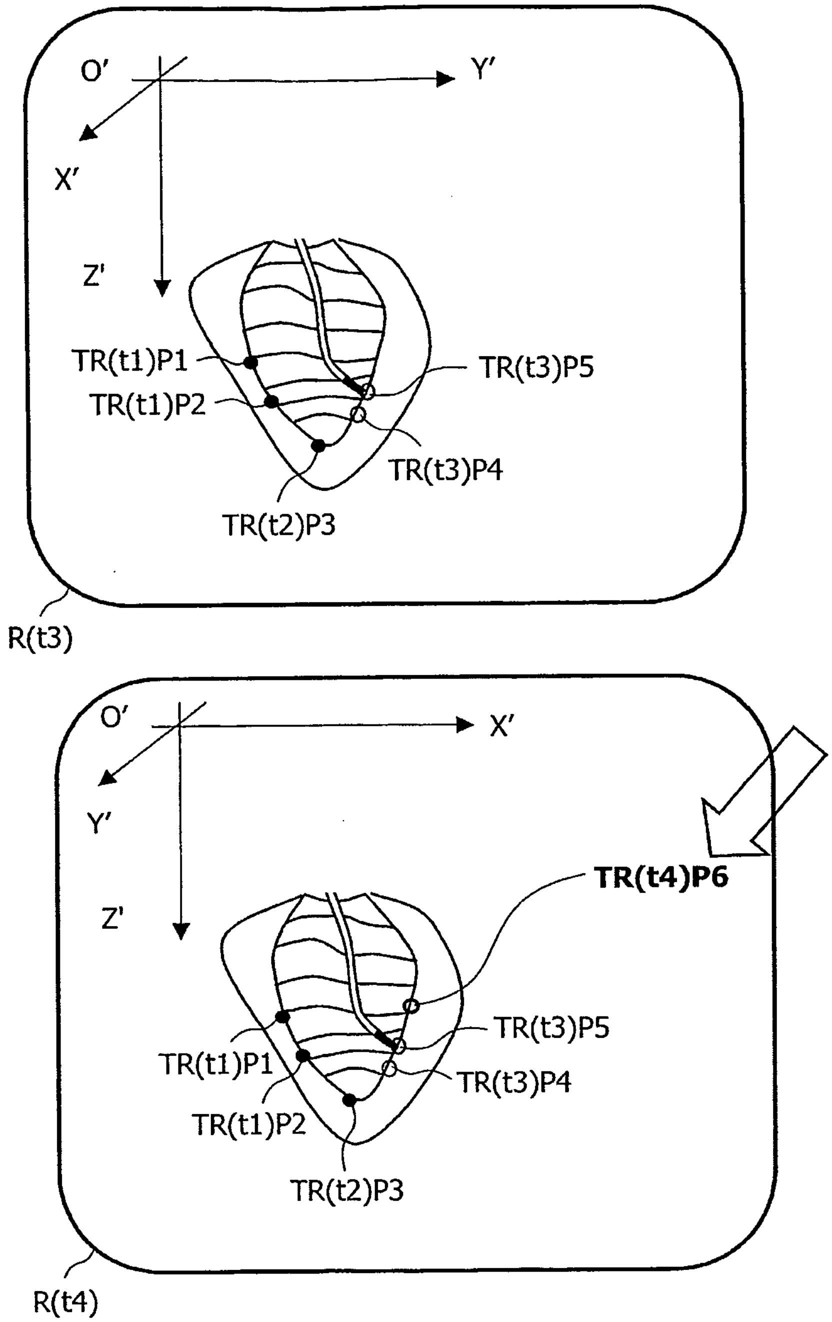


FIG.6



O'
Y'
X'
Z'
TR(t1)P1
TR(t1)P2
TR(t3)P5
TR(t3)P4
TR(t2)P3
R(t3)
O'
X'
Y'
Z'
TR(t4)P6
TR(t3)P5
TR(t1)P1
TR(t3)P4
TR(t1)P2
TR(t2)P3
R(t4)

FIG.7

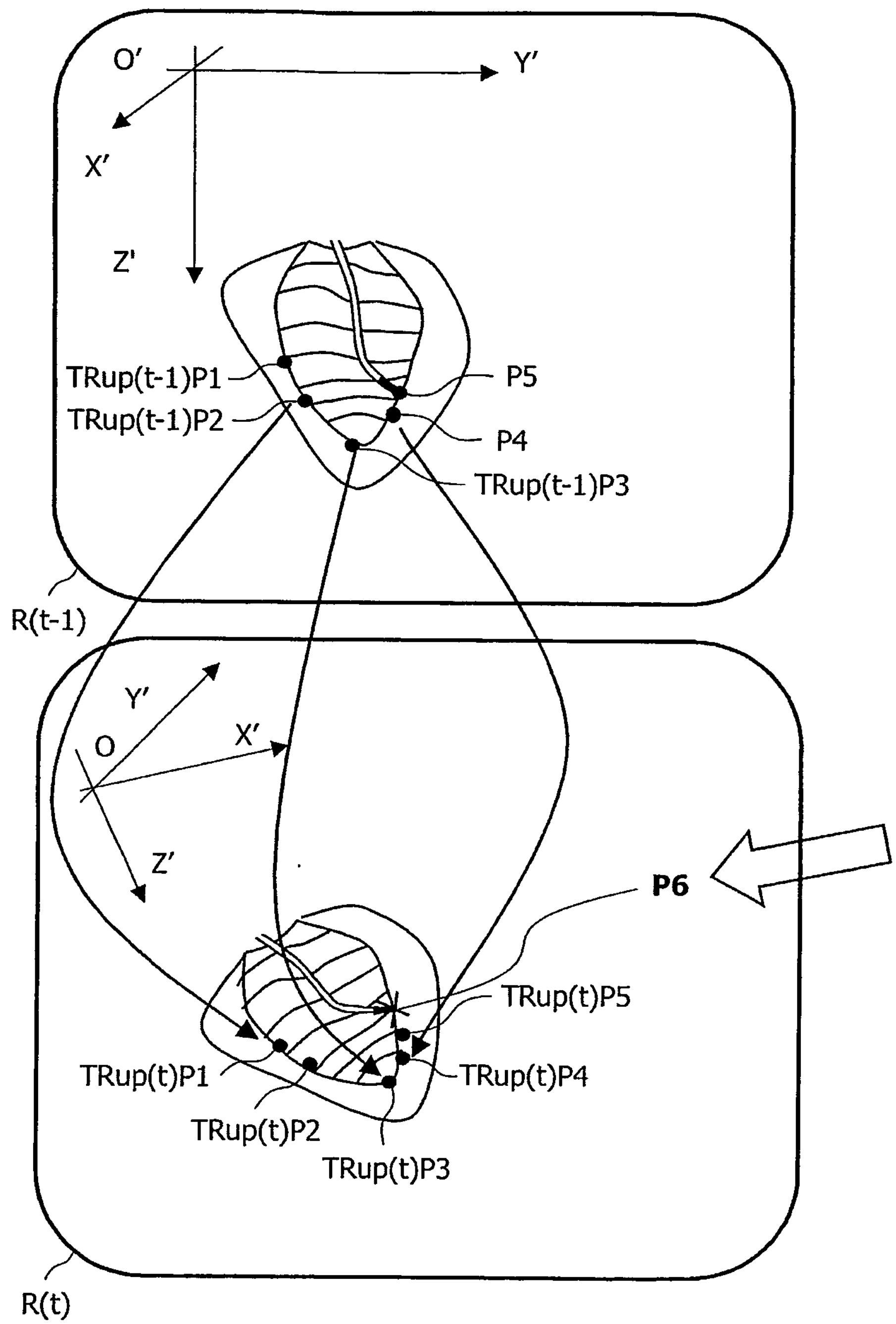

O'
Y'
X'
Z'
TRup(t-1)P1
TRup(t-1)P2
P5
P4
TRup(t-1)P3
R(t-1)
Y'
O
X'
Z'
P6
TRup(t)P5
TRup(t)P1
TRup(t)P4
TRup(t)P2
TRup(t)P3
R(t)

FIG.8

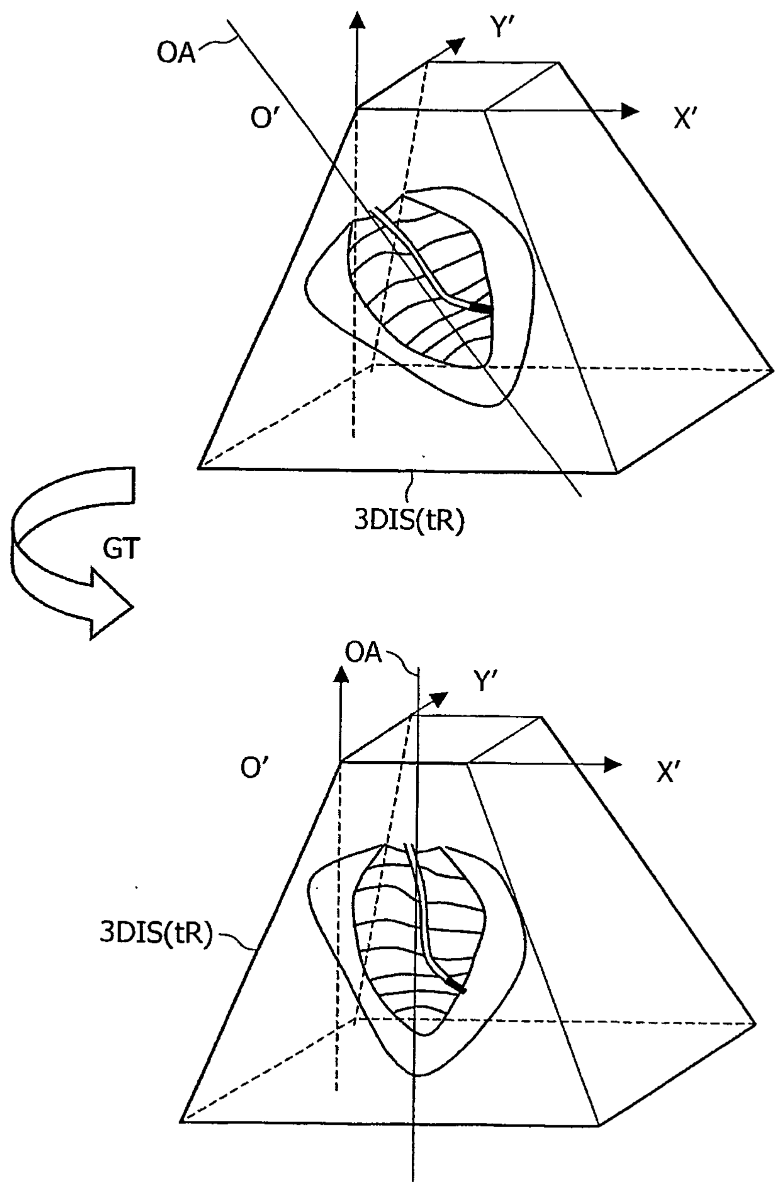


FIG.9

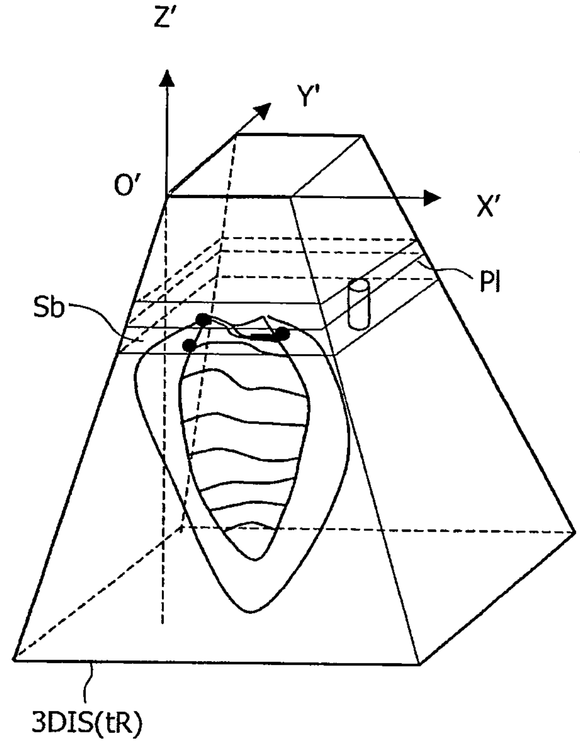


FIG.10A

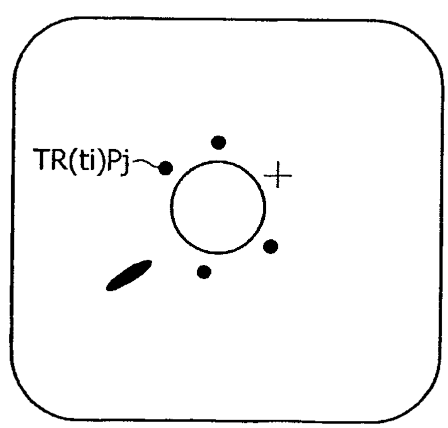


FIG.10B

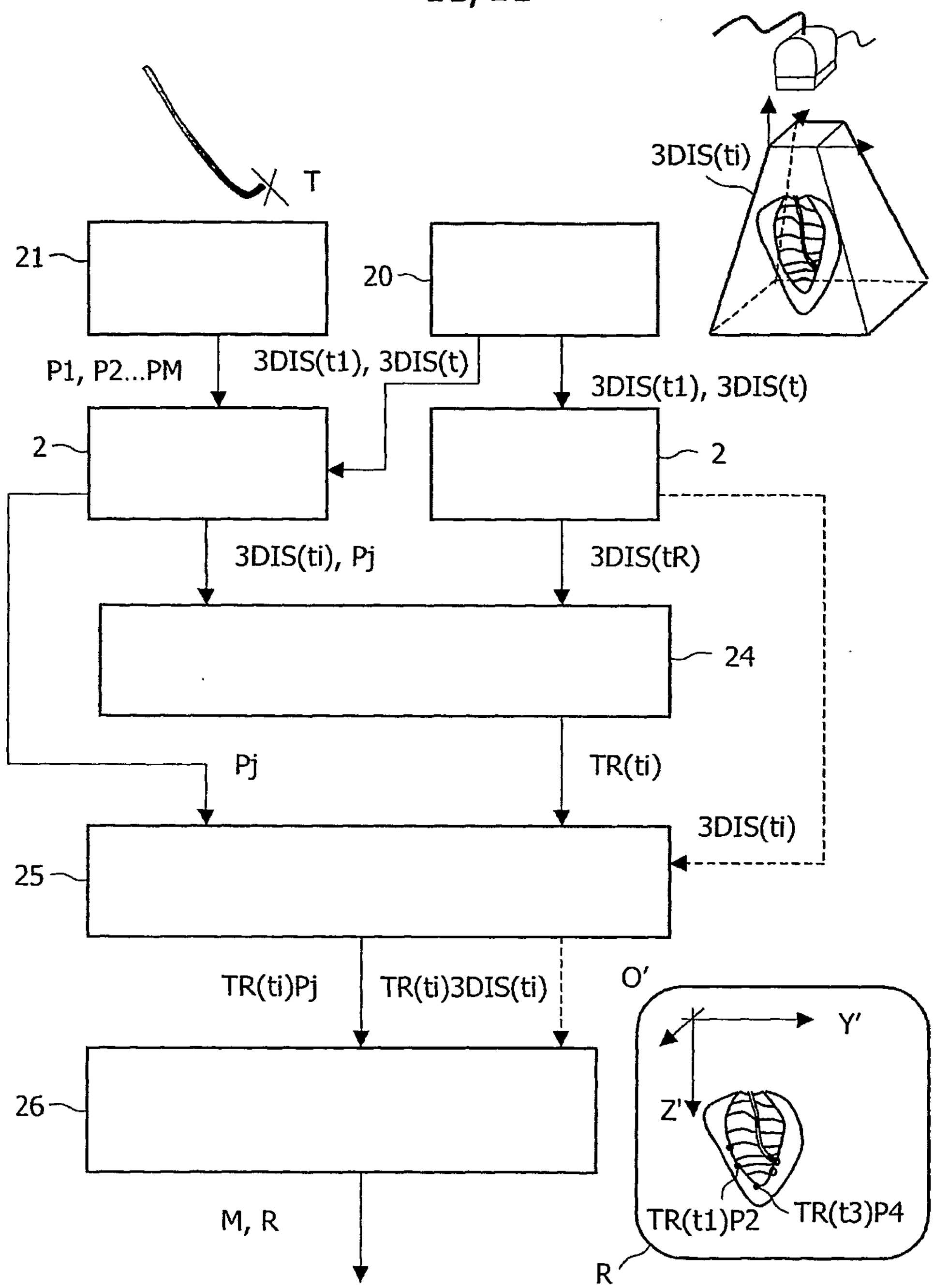

T
3DIS(ti)
21
20
P1, P2...PM
3DIS(t1), 3DIS(t)
3DIS(t1), 3DIS(t)
2
2
3DIS(ti), Pj
3DIS(tR)
24
Pj
TR(ti)
3DIS(ti)
25
TR(ti)Pj
TR(ti)3DIS(ti)
O'
Y'
Z'
26
TR(t1)P2
TR(t3)P4
M, R
R

FIG.11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB2005/051575

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T17/00 A61B19/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06T A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/158477 A1 (PANESCU DORIN) 21 August 2003 (2003-08-21) paragraph '0007! - paragraph '0018! paragraph '0104! - paragraph '0108! -----	1-15
A	US 2004/059217 A1 (KESSMAN PAUL ET AL) 25 March 2004 (2004-03-25) paragraph '0009! - paragraph '0018! -----	1-15
A	US 5 868 673 A (VESELY ET AL) 9 February 1999 (1999-02-09) column 2, line 5 - line 37 column 5, line 10 - line 18 -----	1
A	EP 1 182 619 A (BIOSENSE WEBSTER, INC; BIOSENSE, INC) 27 February 2002 (2002-02-27) cited in the application paragraph '0006! - paragraph '0016! -----	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2005	19/08/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Abraham, V

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2005/051575

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 16
because they relate to subject matter not required to be searched by this Authority, namely:

Rule 39.1(iv) PCT - Method for treatment of the human or animal body by surgery

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IB2005/051575

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